μwave Schottky Pick-ups for LHC

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Outline

- Recent Tev Schottky results
  - Tune "tracking"
  - Chromaticity measurement
  - Momentum spread measurement
  - Emittance measurement
  - Effects of coupling
- LHC related studies
  - Single bunch resolution for low-intensity pbars
- Conclusions and outlook
- Sales pitch for LHC Schottky

Hardware overview

Measurement system overview

Log plotter
D44

Java GUI
OAC parameter control

VSA app
direct VSA control
T51

Lumberjack
Data logging at various rates

OAC
(Open Access Client)
VSA + gate control, tune fitter, ACNET parameters

Hardware
Pick-ups, amplifiers, gate generators, VSAs

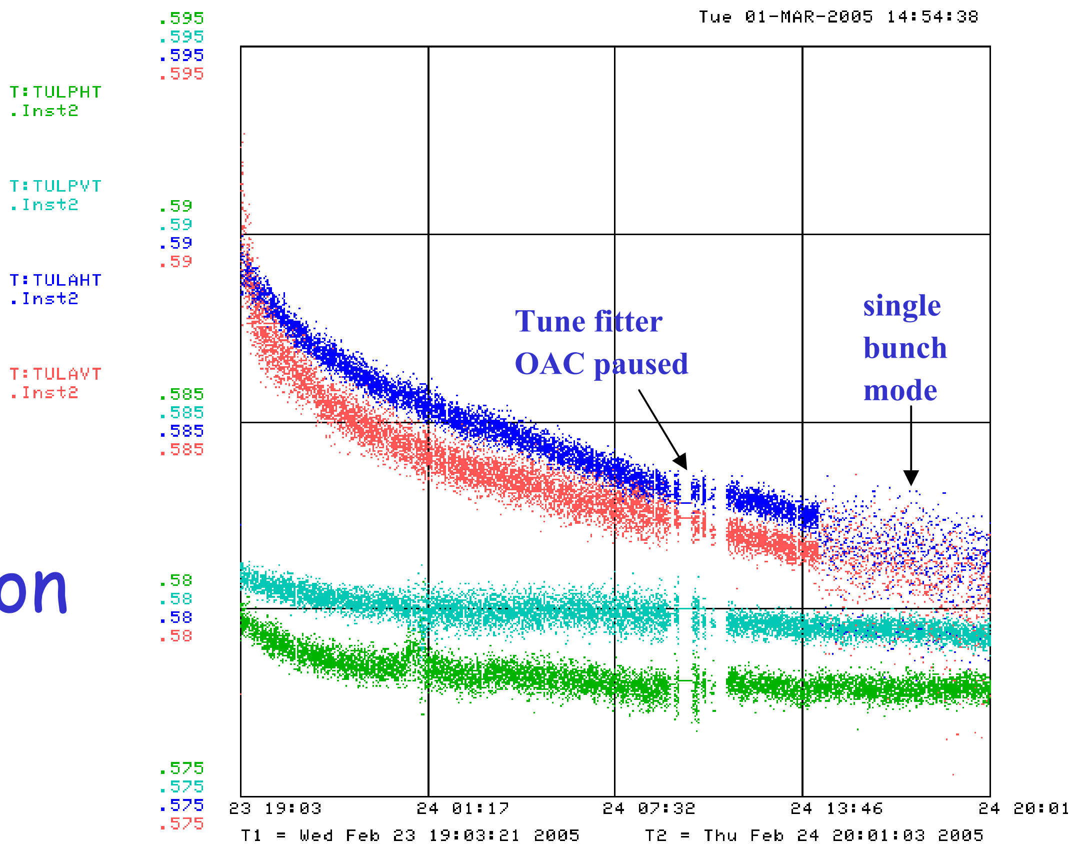
Schottky spectra

System hardware improvements

- Installed high-level FE amplifiers on all channels
- Bypassed noisy signal multiplexer
- Swapped out bad proton horizontal amplifier
- Installed test high-level mixer in proton vertical channel

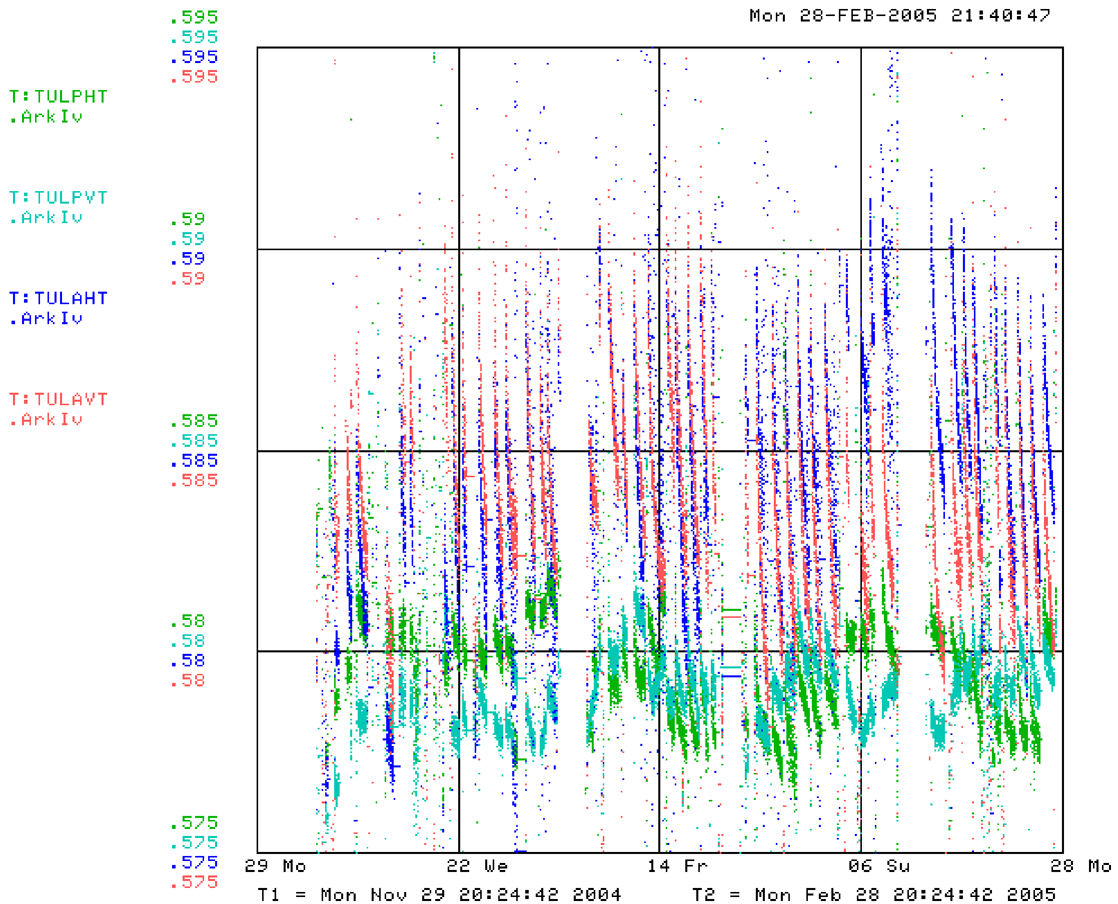
Tune during a store

- Clearly see beam-beam effect (on both protons and pbars).
- Plan to implement slow feedback for pbar tunes based on these signals!

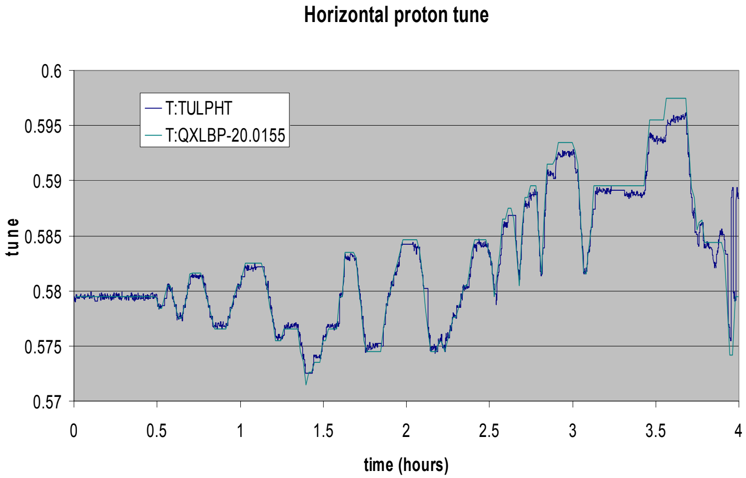


Tev tune history

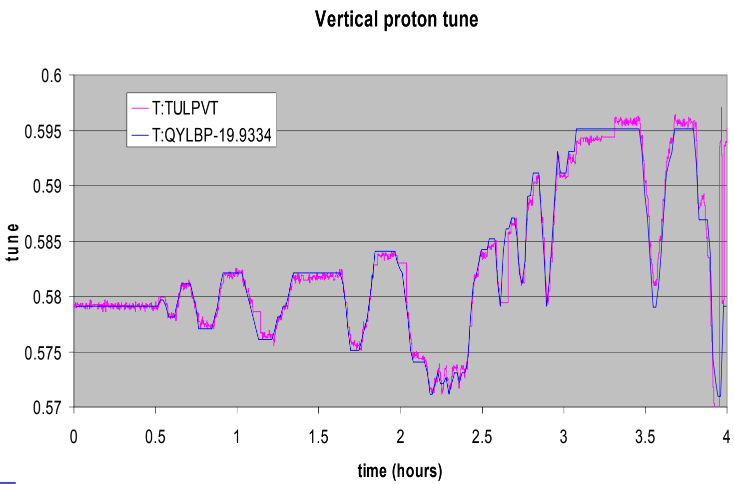
- Average tunes are logged continuously every store.
- Can use to correlate with efficiencies, lifetimes etc

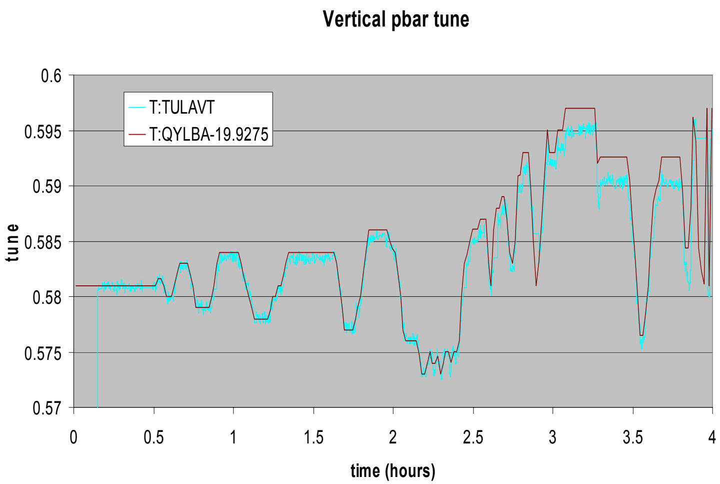


Tune "tracking"



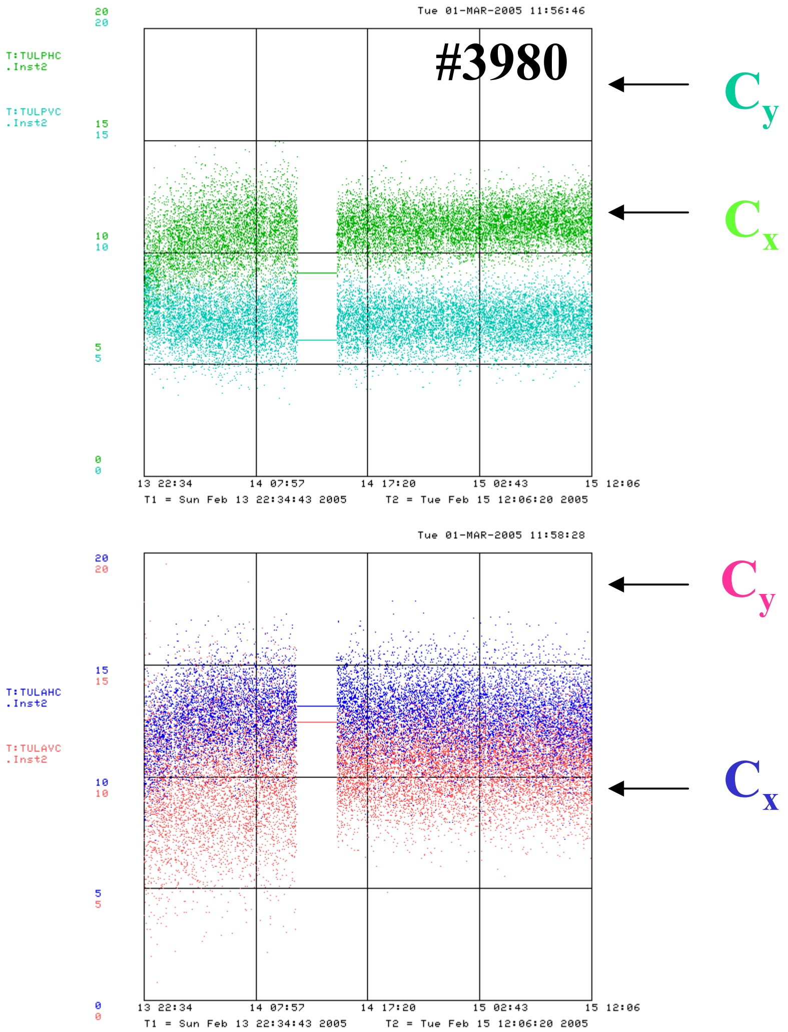
- Measured tune tracks changes in set tunes very well.





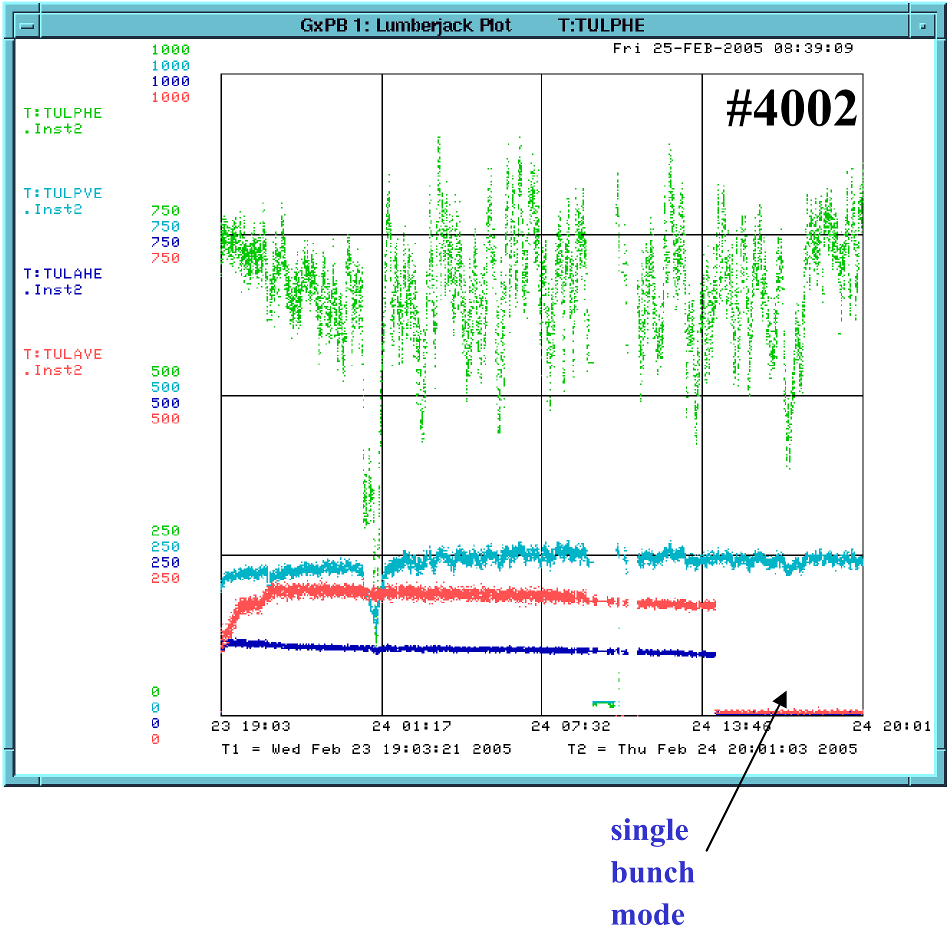
Chromaticity

- Hard to make parasitic comparative measurements → systematic study not done.
- Chromaticities measured at 980GeV during a store compared to traditional measurement (on next ramp).
- Appear to be missing factor ~2 in vertical plane for both species.
- Not yet understood (could be real, could be a instrument problem).



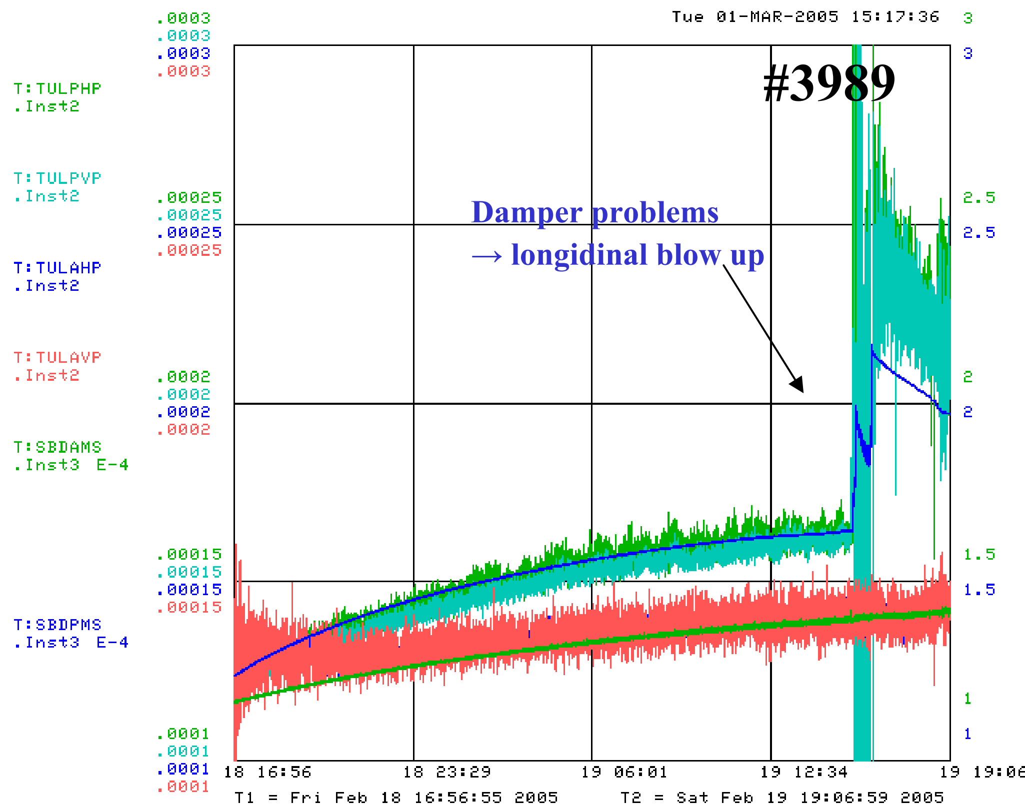
Emittance

- Hoizontal proton emittance show large fluctuations…
- Still some issue with pbar emittance early in store…
- Tried high-level mixer. No improvement so far.



Momentum spread

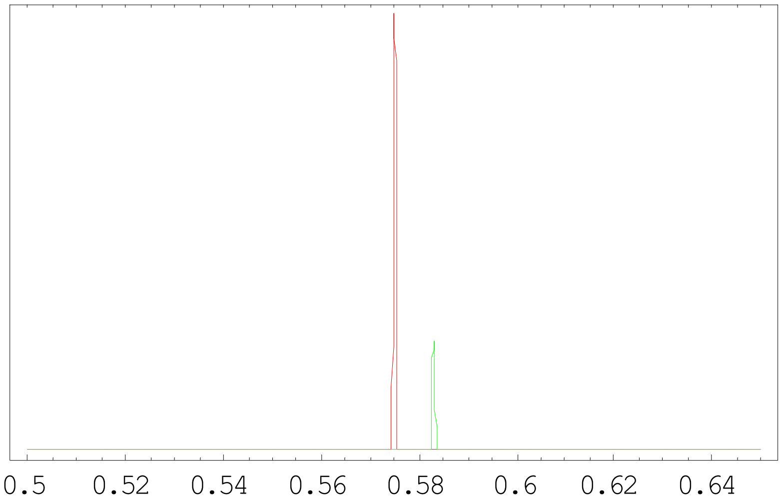
- Measurement of momentum spread show good agreement
- Some issues early in store for pbars (S/N ?).

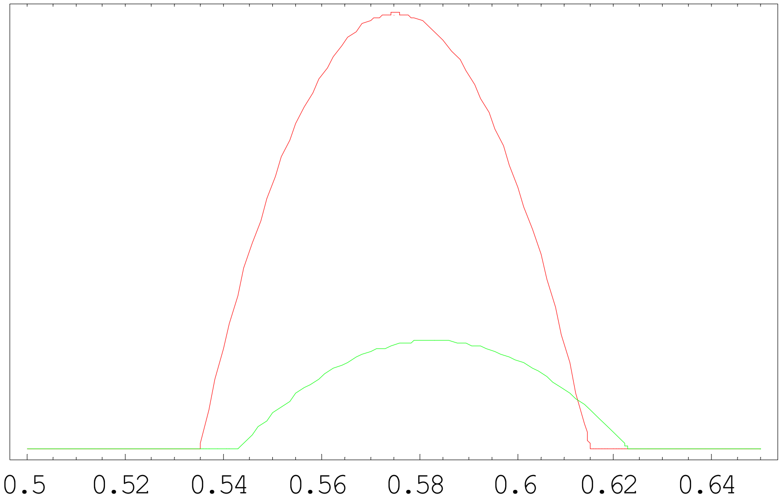


NO fudge factors!!!

High frequency vs low frequency Schottky

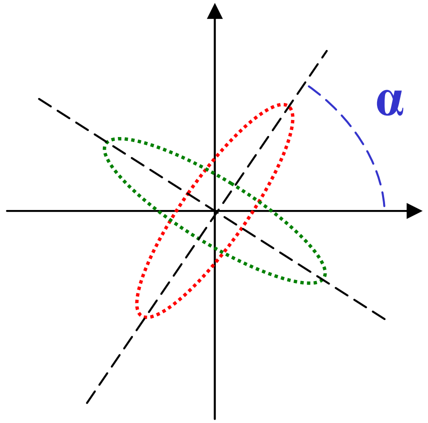
- In a low frequency Schottky spectra, can separate normal modes by frequency
- Microwave Schottky rely only on directional (hor/ver) sensitivity.

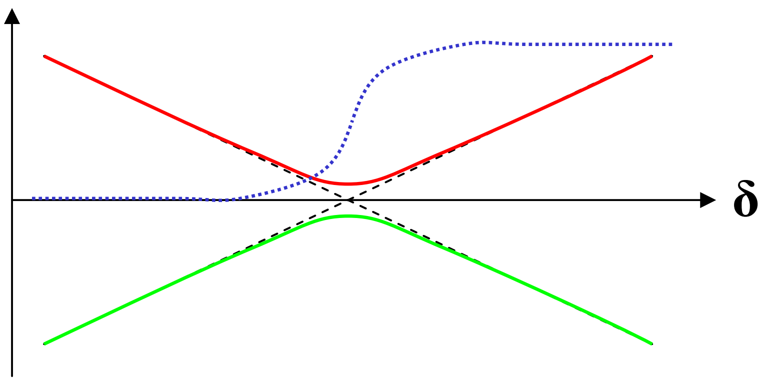




Simple coupling theory

- Measured tune is a weighted average of the two modes.
- Weight is given by inclination angle a.
- Tends to bring measured tunes back together.
- Cancels coupling tune separation exactly in simple model.
- "We measure set tunes"



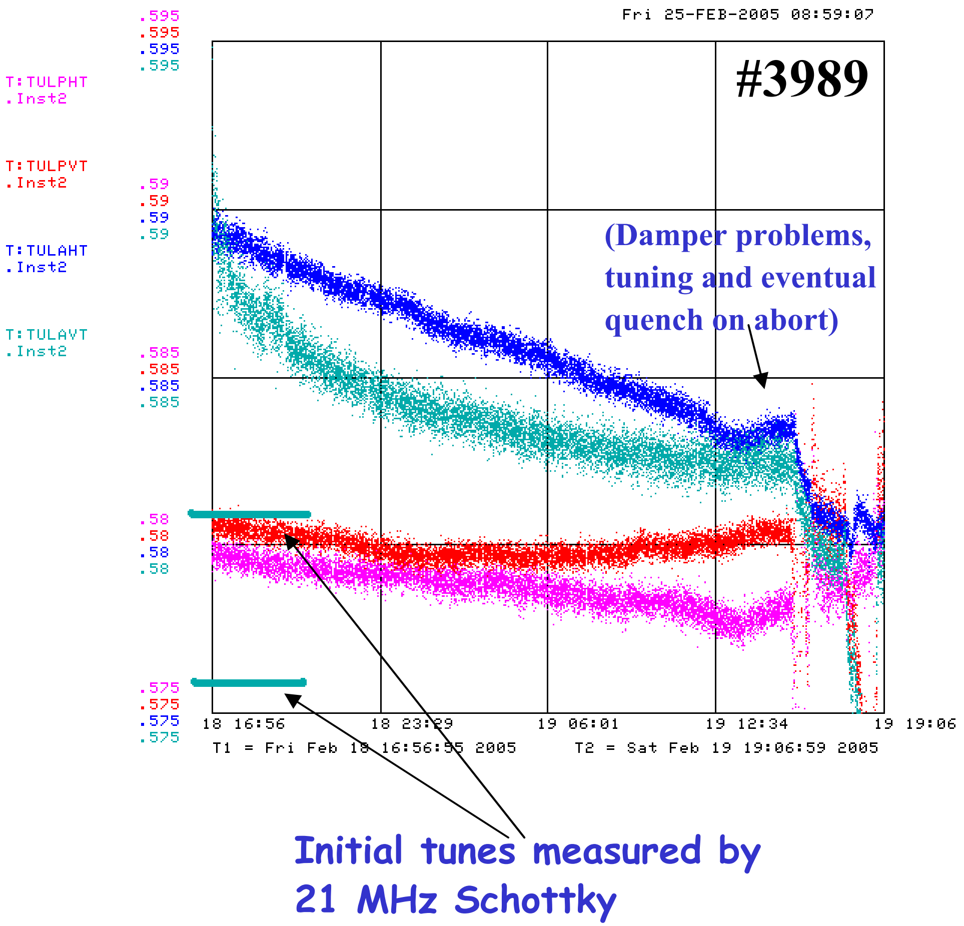


http://beamdocs.fnal.gov/cgi-bin/public/DocDB/ShowDocument?docid=1576

Coupling observations

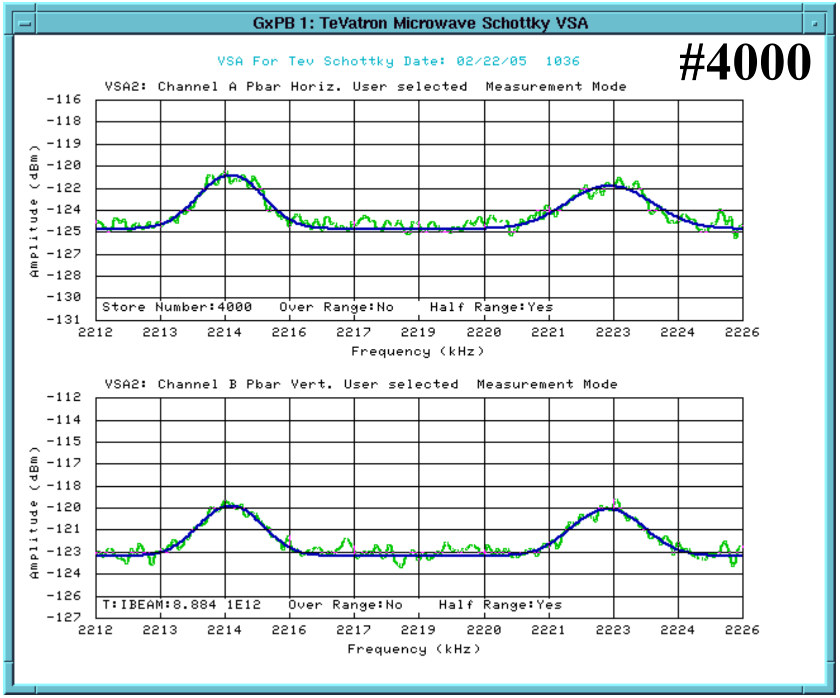
- Difference in measured tunes from 21MHz and 1.7 GHz Schottky show effect of coupling.
- More detailed analysis to follow, using e.g. measured coupled beta functions.

NB. Coupling affects emittance and chromaticity as well



Single pbar bunch measurements

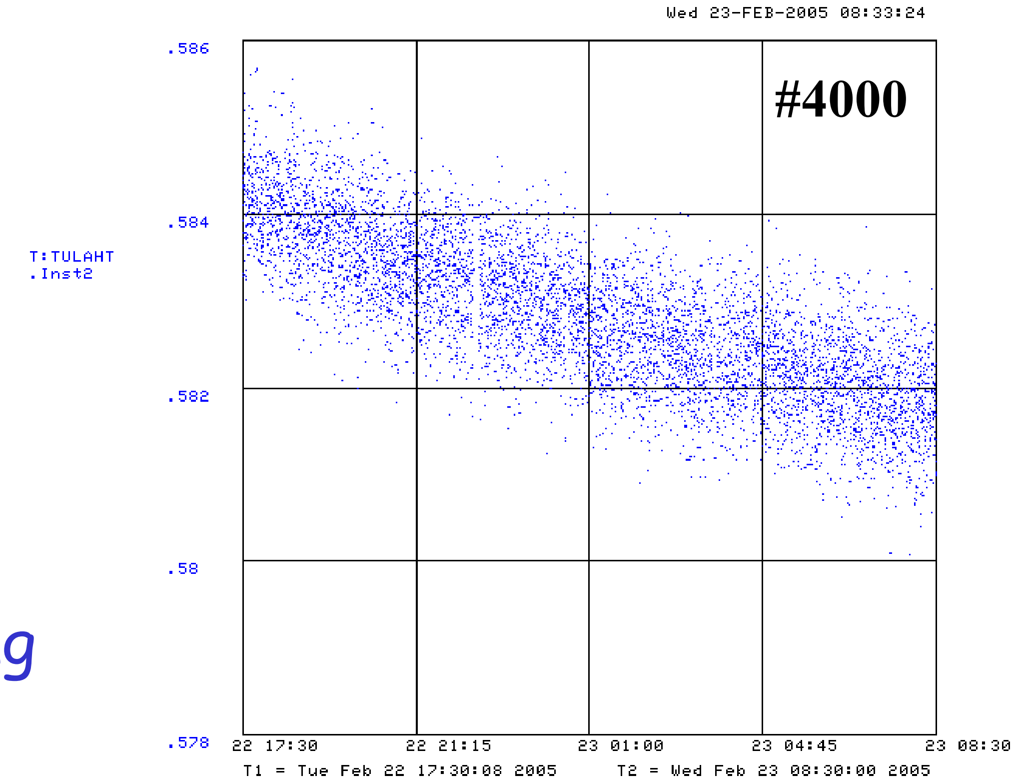
- Found that OAC auto-ranging was not working in an optimal way.
- With manual tuning, got good signal from single pbar bunch at end of store.



Pbar bunch #29
Intensity: 19 10^9
Emittance: ~17 π mm mrad

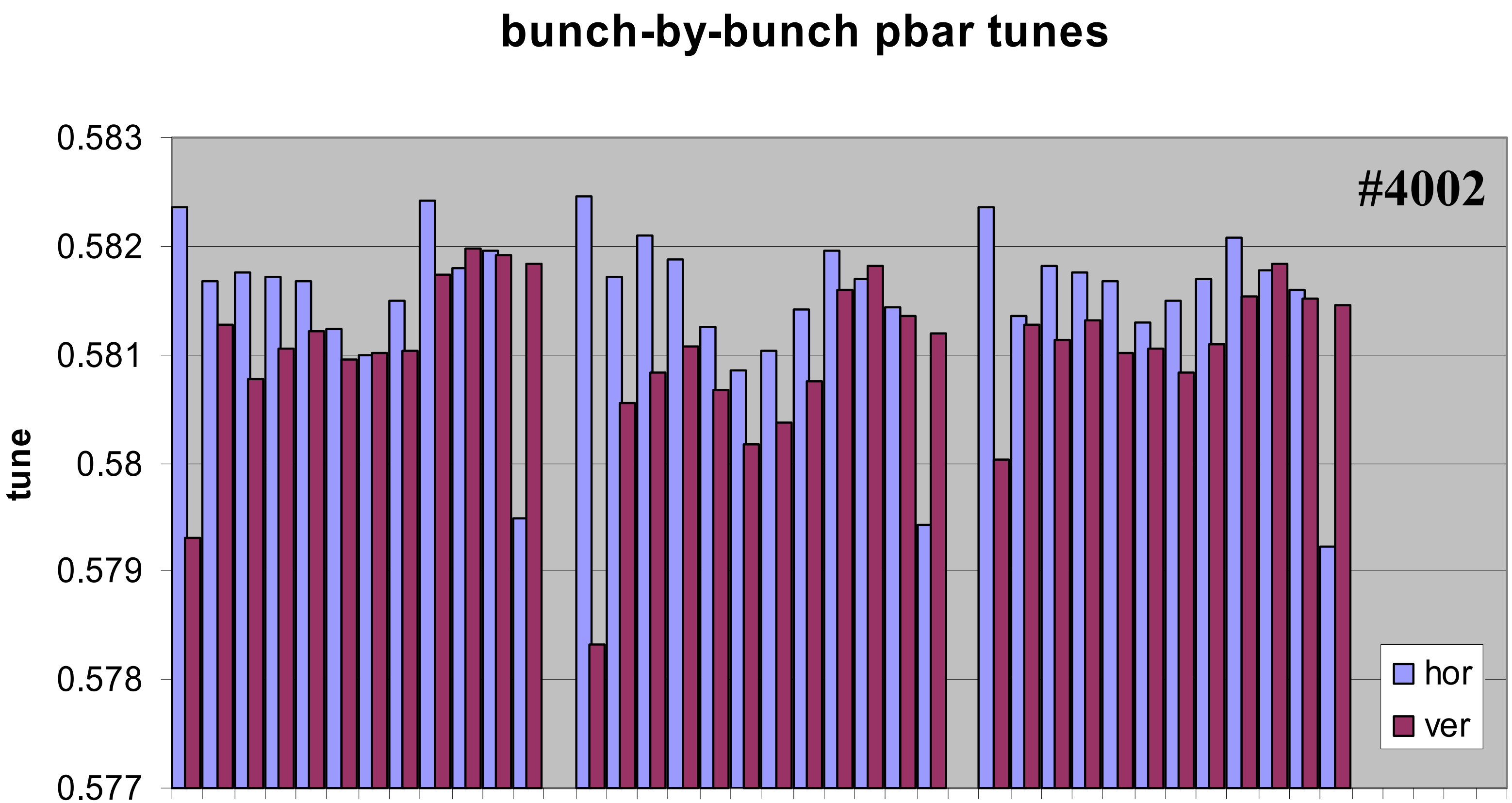
Single pbar tune

- Ran tune fitter on single pbar bunch with manual input gain control.
- Observed tune sensitivity of 5 10^{-4}, and good momentum agreement.
- Implemented triggering of VSA internal auto-ranging every 20 mins.



Bunch intensity: 17 10^9
Emittance: ~17 π mm mrad

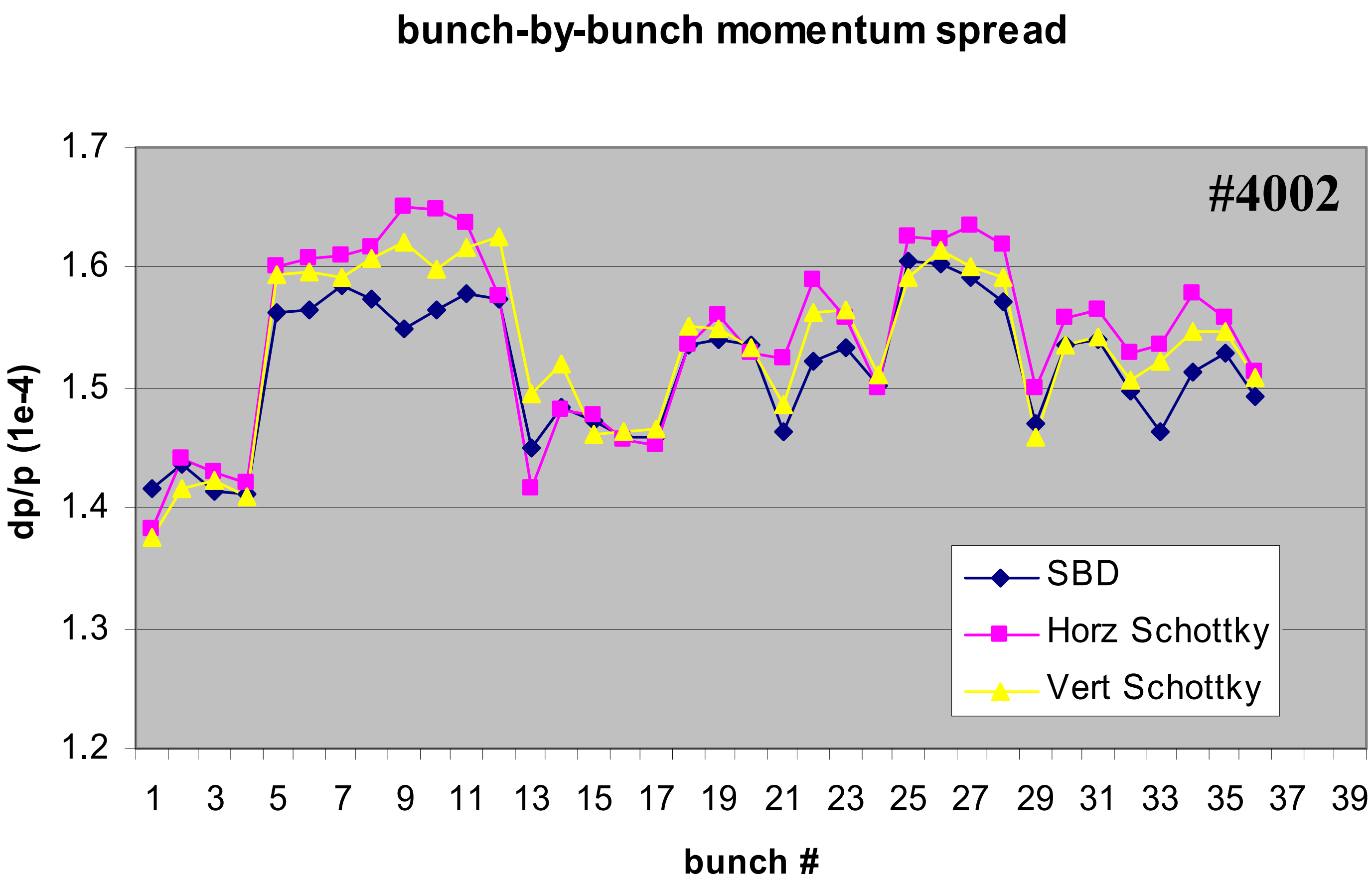
Single bunch tunes



Bunch intensities: 15-40 10^9 Emittances: 7-17 π mm mrad

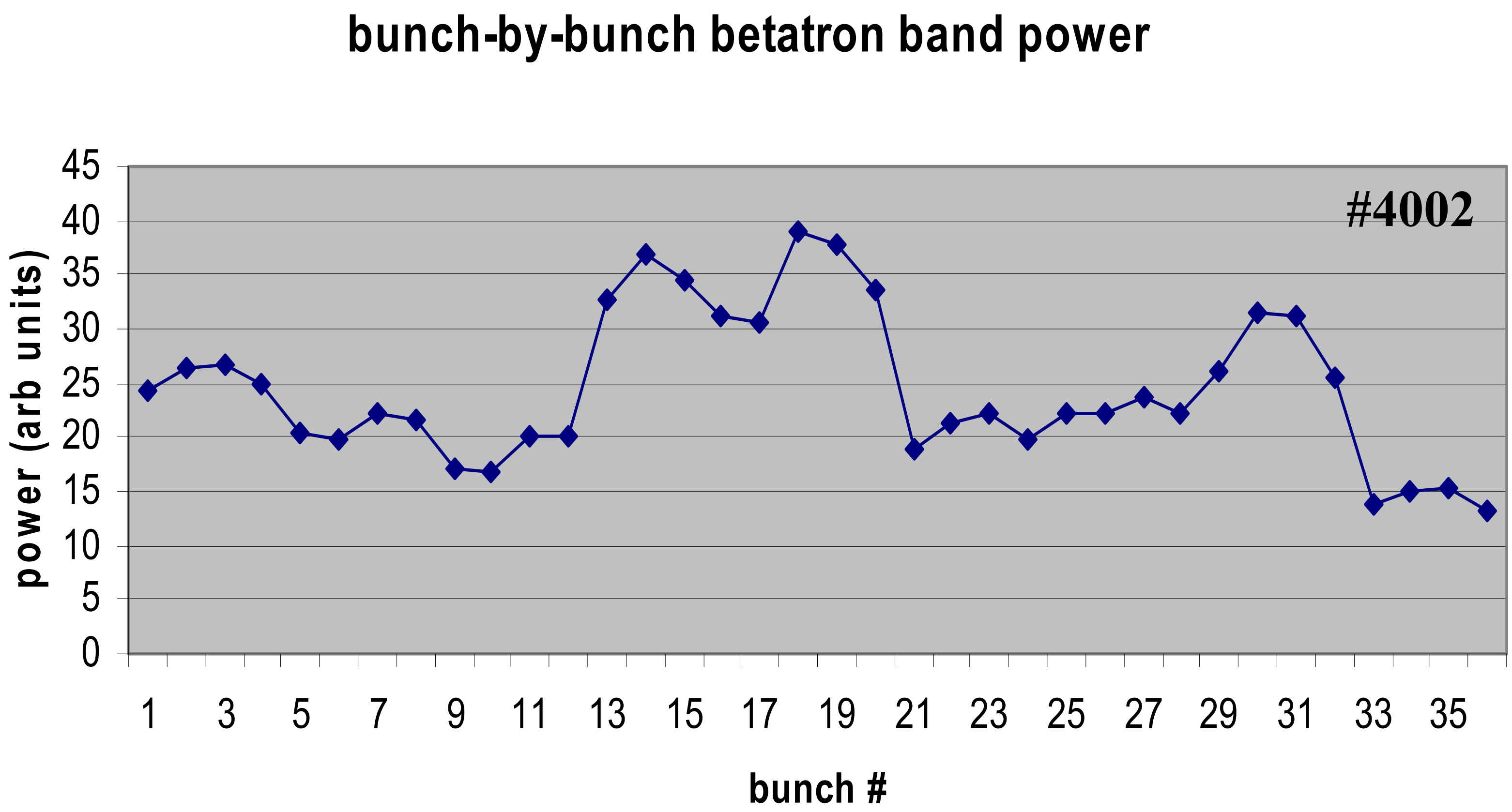
Note characteristic beam-beam signature on first and last bunches in each train

Single bunch momentum spreads

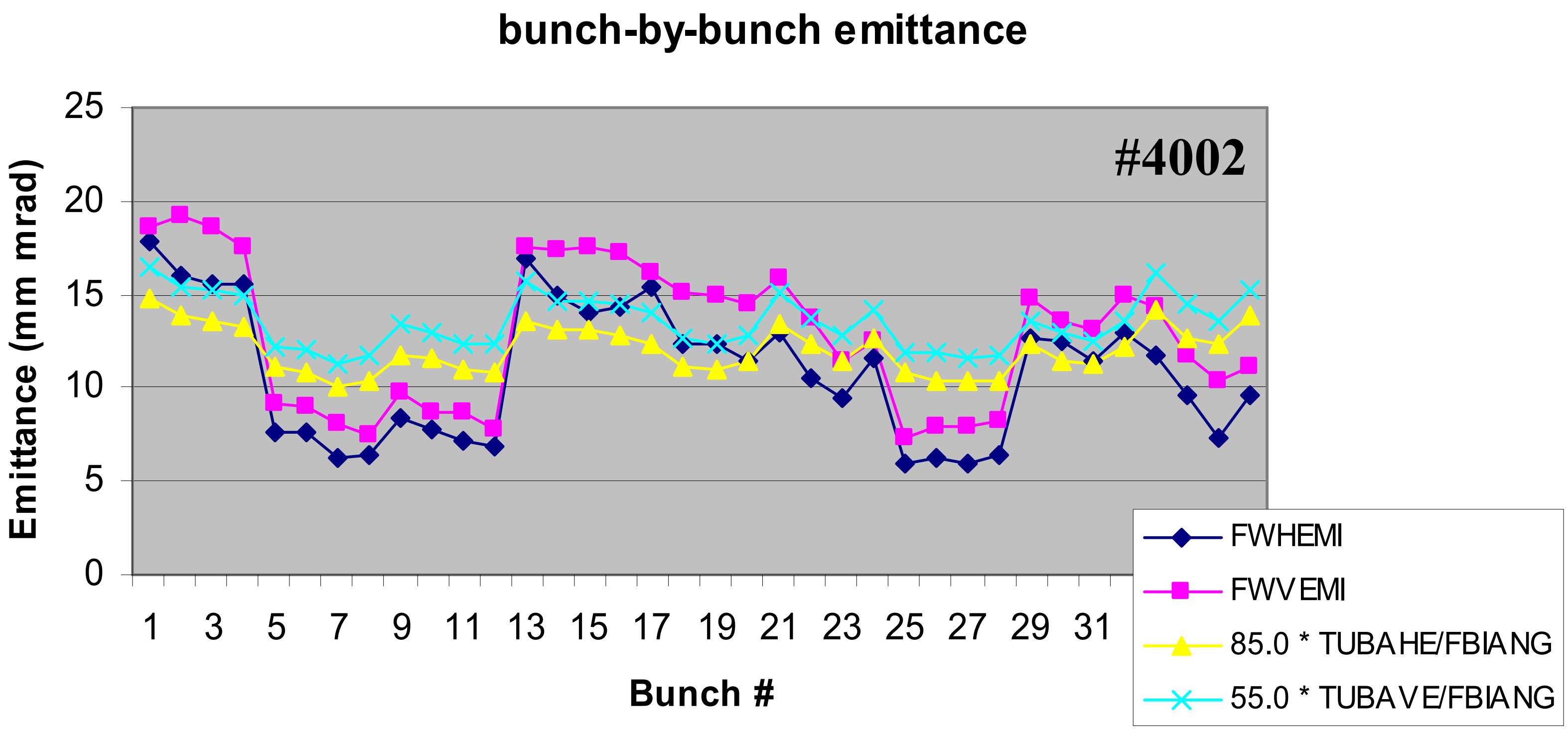


NO fudge factors!!!

Single bunch emittance



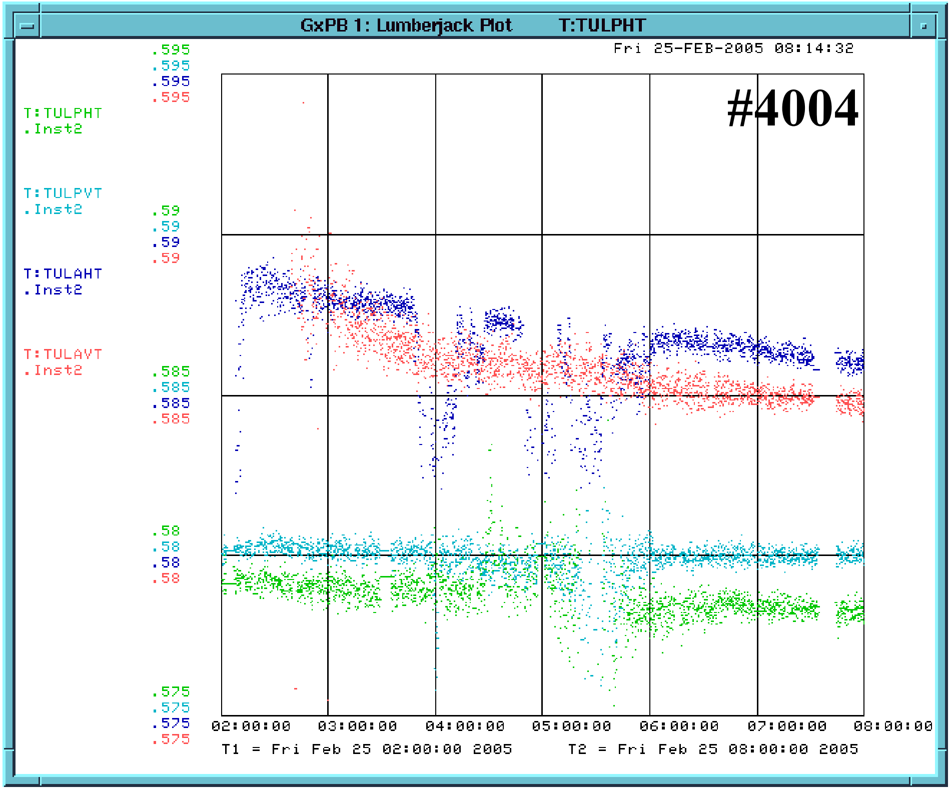
Single bunch emittance



NB. Arbitrary relative scaling (uncalibrated).

Implementing new auto-ranging

- Still some problems with auto-ranging.
- Found that one VSA channel was broken, will send for repair.
- Hopefully, 'proper' ranging will remove some of the strange effects (proton emittance, pbar noise floor…)



Remaining issues

- Understand pbar noise floor early in store
- Understand cause for proton emittance fluctuations
- Understand ramp data…

Conclusions

- Can measure tune of a single 15 10^9 pbar bunch to 5 10^{-4}!!!
- Tune measurement is affected by coupling, in a "predictable" way.
- Very good momentum spread agreement.
- Qualitative emittance agreement for pbars, need to understand proton signals better.
- Chromaticity measurement need more work.
- Considering implementing slow tune feedback based on 1.7 GHz Schottky readings.

LHC sales pitch

LHC Project Document No.

LHC-B-ES-0009 rev 1.0

5. EXPECTED TOLERANCES ON THE OBSERVABLES/PARAMETERS

The analysis of the expected tolerances of the beam dynamics to variations in the beam parameters is done to identify the requirements on accuracy for the instruments.

5.1 TUNE AND TUNE SPREAD

Tracking studies at injection (LHV v6.0, [15]) show that the LHC working point is located almost at the centre of a stability island with a width corresponding to $\Delta Q=\pm 0.010$. The tolerance on the tunes can be deduced from this observation, after subtracting tune spreads and modulations [12, section 2.3.2]: $2\ 10^{-3}$ for the amplitude detuning, $2\ 10^{-3}$ for the chromo-geometric detuning $2\ 10^{-3}$ for the linear part of the chromatic tune modulation and $1\ 10^{-3}$ for the non-linear part. This leaves a tolerance $\Delta Q=\pm\ 3\ 10^{-3}$ for the adjustment of the central betatron tunes at injection.

In collision, the machine operates closer to the diagonal with a tune split of Q_y-Q_x=0.01, which corresponds roughly to the tune spread induced by the beam-beam effects. A safe operation of the LHC in collision requests a control of the betatron tunes with an accuracy better than ΔQ=0.001, i.e. better than 10% of the tune separation.

Several mechanisms may induce a tune spread amongst the bunches:

- The electron cloud produces a tune shift which depends on the bunch position in a batch. A tune shift of the order 0.005-0.01 along a train has been observed at KEKB and in the SPS [16] and should be expected during the beam scrubbing.
- The Pacman effect induces a beam-beam linear tune shift which depends on the beam position. Its value is 0.001 for the nominal alternate crossing and might reach 0.003 if other crossing schemes remain possible [8].

12.6 BUNCH SELECTIVITY FOR THE MEASUREMENTS

In most cases, the beam average of the tunes, chromaticities,... are appropriate. This mode should be considered as the priority mode of operation for LHC in terms of availability and accuracy The identification of the e-cloud effect would benefit from a bunch-by-bunch measurement of the tunes. When the machine performance reaches the nominal level, a bunch by bunch measurement of the tunes and possibly of chromaticity is likely to become necessary. The measurement of the amplitude detuning and of the beam-beam transfer function requires as well a bunch-by-bunch measurement. The bunch-by-bunch mode is thus demanded to be available from the beginning as a commissioning tool, whether or not the precision targets are initially reached

- Microwave TW Schottky provides passive bunch-by-bunch tune measurement (and more).
- CERN is requesting this!

Final words of ancient wisdom

- The LHC will undoubtedly encounter numerous problems during commissioning and early running. Many are foreseen, some may well be surprises.
- Having proper instrumentation there <u>from the start</u> will certainly help diagnose these issues and reach higher luminosity, faster.

LARP project criteria

- ☑ R&D – we are still trying to understand the signals in the Tevatron.
- ☑ Commissioning – would require people on location to commission devices.
- ☑ Luminosity – will help understand the machine, and hence increase luminosity.

Beam parameters

	Tevatron	LHC
Revolution frequency	48 kHz	11 kHz
Synchrotron frequency	34 Hz	23 Hz
Momentum spread	10^{-4}	10^{-4}
Bunch length	1.7 ns	0.3 ns
Slip factor	0.0029	0.0003
Base tune	0.575	0.3
Aperture	76 mm	44 mm
Bunch intensity	3e11	1e11

$$\frac{\Delta f}{f} = \frac{\Delta p}{p} \times n \times \eta$$

$\uparrow$ x4 $\quad\downarrow$ x10

- What frequency to use in LHC?
  - Bunch length indicates approx x6 higher frequency
  - Frequency spread -> x2
  - Aperture may not allow more than about x2

How the tunes are measured

- Tev 1.7 GHz Schottky measure tunes as the center-of-mass frequency in the betatron band.
- If there is coupling, this will be a weighted average of the two normal mode contributions, with a relative weight given by a, the normal mode inclination angle.

Coupling cont'd

- Coupling will also affect emittance and chromaticity measurements (but not momentum spread).